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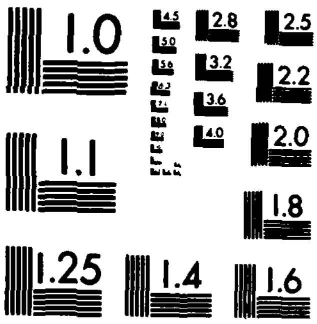

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BY

BRUCE W. HAMILL

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BRUCE W. HAMILL

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Milton S. Eisenhower Research Center
Applied Physics Laboratory
The Johns Hopkins University
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Laurel, Maryland 20707

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Recent advances in the artificial intelligence technology of knowledge-based expert systems have captivated the imaginations of designers, sponsors, and suppliers of computer-based systems in government and industry as well as researchers in university and non-profit laboratories where the technology originated. An expert system is essentially a way to capture the knowledge and expertise of a subject-matter expert and transfer it to a computer program in hopes of creating an "intelligent" computer system that will emulate

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ABSTRACT (cont.)

the problem-solving and decision-making performance of the expert. Such systems are being built to serve as intelligent advisors and decision aids in a wide variety of application areas. We discuss conceptual issues underlying expert system design, with references to current psychological and artificial intelligence literature, and urge consideration of these issues before undertaking development of expert systems. *Author-assigned keywords include: Knowledge-based systems; Knowledge acquisition; Knowledge representation; Mental models; and Decision aids.*

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PSYCHOLOGICAL ISSUES IN THE DESIGN OF EXPERT SYSTEMS

Bruce W. Hamill

Milton S. Eisenhower Research Center
Johns Hopkins University Applied Physics Laboratory
Laurel, Maryland 20707

ABSTRACT

Recent advances in the artificial intelligence technology of knowledge-based expert systems have captivated the imaginations of designers, sponsors, and suppliers of computer-based systems in government and industry as well as researchers in university and non-profit laboratories where the technology originated. An expert system is essentially a way to capture the knowledge and expertise of a subject-matter expert and transfer it to a computer program in hopes of creating an "intelligent" computer system that will emulate the problem-solving and decision-making performance of the expert. Such systems are being built to serve as intelligent advisors and decision aids in a wide variety of application areas. We discuss conceptual issues underlying expert system design, with references to current psychological and artificial intelligence literature, and urge consideration of these issues before undertaking development of expert systems.

INTRODUCTION

Feigenbaum (1982; see Gevarter, 1982) has described a knowledge-based expert system as "...an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution." Expert knowledge, in the forms of factual information, procedural rules, meta-rules (rules for applying rules), heuristics (rules of plausible reasoning or good guessing), and relawions among all of these, all of which are elements of an individual's knowwedge and experience in his field of expertise, can be captured and transferred to an "intelligent" computer program which can then, using inference procedures, emulate the problem-solving and decision-making performance of the human expert whose knowledge/experience is represented in the program. The knowledge and inference procedures contained in the program can thus be thought of as a model of human expertise that can be used in a decision-aiding, advisory, or even autonomous decision-making capacity.

One of the most important results of the early work on intelligent systems was the realization that it is the contents of the knowledge base, rather than the control structure (rule interpreter or "inference engine"), that gives an expert system its power (Feigenbaum, 1980). The control structure may be a relatively simple inference engine with a limited set of functions; the knowledge base, on the other hand, may be a very extensive set of facts, rules, meta-rules, and relations among them. Given external data with which to work, the control structure guides the system's search through the knowledge base to produce intelligent decisions and problem solutions comparable to those of a human expert in the content area. As is the case with human experts' knowledge, the knowledge base of an expert system may contain both well-defined and ill-defined facts and rules; the system will perform as effectively as the knowledge base permits, and facts, rules, and relationships may be added or deleted as needed to improve system performance. System development requires a somewhat circumscribed content area and a knowledgeable individual (or individuals) whose recognized expertise in the content area may be elicited and codified for the knowledge base of the expert system.

Expert systems are designed to operate in a manner analogous to that of humans performing the same tasks. They employ facts and decision rules that are, in fact, obtained from humans knowledgeable about the application areas in which they operate, and their internal functions are based on procedures that mimic human processes. System programs and data may be written in symbolic as well as numeric form; the artificial intelligence community's LISP language and its variants are most suitable for expert system development, although new languages like PROLOG and various object-oriented languages are also starting to be used for the purpose.

In addition to making decisions and solving problems, expert systems are capable of keeping track of the facts, rules, and procedures they use to arrive at decisions and solutions, and to display all of these on demand. This permits users to know how a system arrives at its conclusions and to decide whether the approach is valid; changes may be made to the system to correct deficiencies discovered by this means. In principle (but not yet in practice), an expert system should be able to prepare a synopsis or summary of its rationale for its conclusions, thereby providing the user with helpful intermediate information for his consideration in selecting among alternative courses of action.

KNOWLEDGE ENGINEERING ISSUES

Knowledge-based expert systems can, in principle, be built for any application area in which there exist facts and heuristics that are currently used by human experts for solving problems and making decisions. In this sense, if the requisite knowledge and expertise can be captured and transferred to an expert system's knowledge base, there are no limits on potential application areas.

Knowledge engineering is a term used to refer to the entire process of building knowledge-based expert systems. This process includes: designing and implementing the framework of the expert system, including its computer operating system environment, software features, memory structure, and user interface; acquiring from knowledgeable experts and other sources the expertise that is to be embedded in the expert system; converting that expertise to a form appropriate to representing it in the structure of the system; devising inference procedures for utilizing the system to make decisions and solve problems; and performing other tasks required to design and operationalize such systems. As such, knowledge engineering is an occupational specialty that bridges a number of disciplines, including artificial intelligence, cognitive psychology, computer science, systems engineering, and human factors, among others.

Acquisition, Representation and Use of Knowledge

The principal scientific and practical issues in building a knowledge-based expert system involve (1) acquiring domain-specific knowledge from recognized experts, (2) representing that knowledge appropriately in the system's knowledge base, and (3) using that knowledge effectively in decision making and problem solving. These three issues are interrelated in a symbiotic manner.

Knowledge Acquisition. While certain bodies of factual knowledge about most content areas can be found in such sources as textbooks, knowledge and expertise gained through experience are not usually available from such sources; they must be obtained from acknowledged experts. This is currently done by having experts respond to queries about hypothetical situations, either through the experts' direct interaction with a knowledge-based system or, more typically, with the assistance of an intermediary (the knowledge engineer) who can transfer the experts' knowledge into the system's knowledge base. Of course, this transfer, involving as it does people other than experts themselves in the interpretation of knowledge and expertise, together with the use of verbal reports of experts (see Ericsson and Simon, 1980), offers the potential for entering misinformation into a knowledge base; thus some mechanism for validation of knowledge entered into the system is required. It may also be possible to derive knowledge in other ways, such as in simulation and gaming environments where knowledge might be captured by observing the behavior of participants responding to situations arising in scenarios requiring decision making and problem solution. In any case, the knowledge that is to power the system is resident in the heads of the experts and must be transferred in usable form to the knowledge base of the system.

Knowledge acquisition efforts are necessarily guided by explicit and implicit assumptions about the nature and organization of the knowledge to be elicited from an expert. The Committee on Human Factors of the National Research Council (1983) has identified a number of important research issues in the area of elicitation of information from experts. Among those issues are the following: (1) ensuring a common frame of reference to ensure that the knowledge engineer and the expert are talking about the same thing; (2) matching questions to mental structures to ensure compatibility between the way in which knowledge is organized and the way in which that knowledge is elicited; (3) clarifying and assessing information quality, since people usually have only partial, incomplete appreciation of the extent of their knowledge, a condition that expresses itself in overconfidence that is impervious to most debiasing efforts except intensive training; (4) ascertaining the fidelity of representations produced by extant elicitation systems and the conceptual systems they are intended to model, as by determining whether formally equivalent ways of eliciting the same information produce the same or different responses, or by assessing experts' ability to judge the completeness of a representation; (5) detecting reporting biases reflecting unintentional or deliberate misreports or wrong answers; and (6) detecting distortions in the reporting of past events, since hindsight can produce exaggerations of what could have been or was known in foresight at the time of an event, and since experts may have overemphasized particular events, leading to misinterpretations of the importance and generality of causal forces involved.

Each of these issues has a potential impact on knowledge acquisition and must therefore be considered in developing techniques and protocols for practical applications as well as for guiding analytical and empirical research efforts.

Knowledge Representation. For knowledge to be used in a system, it must be represented in some fashion in the system's knowledge base. Considerable effort has been devoted by psychologists and artificial intelligence researchers to understanding the nature and organization of human semantic and event memory (see, e.g., Anderson, 1983; Bobrow and Collins, 1975; Lindsay and Norman, 1977; Posner, 1973; Schank and Abelson, 1977; Schank and Riesbeck, 1981; Tulving and Donaldson, 1972; Weimer and Palermo, 1974; Wilensky, 1983). Out of this research have come ideas that are now embodied in artificial intelligence software systems.

Knowledge representation research is essentially psychological, in that it requires the investigator to produce an explicit analytical model of the processes being used by the decision maker in response to (sets of) situational requirements (see, e.g., Anderson, 1980; Gentner and Stevens, 1983; Hunt, 1983; Larkin, McDermott, Simon, and Simon, 1980; Pople, 1982; Rasmussen, 1983; Simon, 1979, 1981; Wilensky, 1983). These "mental models" specify components of the decision process in such a way as to afford opportunities to identify relevant variables and to measure them empirically, leading to the possibility of specifying performance criteria for certain of the identified reasoning processes. Such measures are especially valuable for system evaluation and training applications.

The issue of how to represent knowledge in a knowledge base is an important one that has implications for the architecture of a system (see, e.g., Barr, Cohen, and Feigenbaum, 1981-82; Hayes-Roth, Waterman, and Lenat, 1983; Rich, 1983; Sowa, 1984; Winston, 1977, 1984; Woods, 1983). There are a number of possible ways to represent knowledge in an expert system (see Barr, Cohen, and Feigenbaum, 1981-82; Gevarter, 1983a; Nau, 1983). These include: logic, including the propositional calculus and the predicate calculus (see Nilsson, 1971); procedural systems (see Winograd, 1975); semantic networks (see Findler, 1979; Winograd, 1982); directed graphs (see Rich, 1983); production systems (see Waterman and Hayes-Roth, 1978; Winston, 1977, 1984); direct (analogical) representations (see Pylyshyn, 1978; Sloman, 1971); semantic primitives (see Schank and Abelson, 1977; Wilks, 1975); and frames and scripts (see Bobrow and Winograd, 1977; Minsky, 1975; Schank and Abelson, 1977; Winston, 1984), and there may be others.

The particular application influences selection of an appropriate knowledge representation scheme and the architecture that will support that representation. It is important that this selection be done carefully, since there are currently no models of human decision making that are sufficiently general to be applicable to more than well-circumscribed domains. For this reason, the first thing to do in designing an expert system is to analyze the task domain well enough to determine the best structural formalism for representing the knowledge that will reside in the system's knowledge base. It is this decision that will drive decisions about the appropriate system architecture and the nature of the inference engine that will search the knowledge base in the course of problem-solving and decision-making applications; thus, it is this decision that will determine the ultimate effectiveness of the expert system. In short, the system must be designed for the task.

This is an especially important consideration in view of the growing number of system development frameworks available in the marketplace. Each employs some particular formalism(s) for representing and searching through its knowledge base, and, as we have seen above, there are a variety of ways to do this. A given framework may or may not be appropriate to the task at hand. The choice between using an off-the-shelf framework and building a system from scratch must rest upon considerations derived from the task analysis.

Knowledge acquisition and representation must both be done with end users of the knowledge-based system in mind. The users of any knowledge-based system expect it to perform in a manner consistent with their expectations. Decision makers will develop their own mental models of what they understand to be going on in both the decision-aiding system and the decision environment, and they will be using such systems to help them improve their understanding of the situation at hand. In order for the system to be trusted and used, the knowledge base must be so developed that it both contributes to and is consistent with the mental models of the users of the system. For this reason it is most important to determine what those users are doing, how they are thinking, what knowledge they are using, and how and why they are using it to make their decisions and solve their problems. In short, knowledge acquisition and representation research must both be conducted with the active participation of end users.

Knowledge Utilization. Once knowledge has been acquired from experts and represented appropriately in the system's knowledge base, it must be accessed and utilized in making decisions and solving problems. The manner in which the system is to perform these functions influences the design of the control structure that drives its operation, searching through the knowledge base, making use of necessary facts, applying rules, and keeping track of the course the system follows in arriving at satisfactory evaluations, predictions, decisions, and solutions to problems (see Barr, Cohen, and Feigenbaum, 1981-82; Hayes-Roth, Waterman, and Lenat, 1983; Rich, 1983; Winston, 1977, 1984). Knowledge utilization research is a necessary complement to research in knowledge acquisition and representation, since it provides insight into the processes by which knowledge elicited from experts and stored in a knowledge base may be employed in attaining acceptable system performance and in meeting research and operational goals.

CONCLUSION

Expert systems technology has advanced rapidly in the past few years (see, e.g., Duda and Gaschnig, 1981; Duda and Shortliffe, 1983; Gevarter, 1983b; Kinnucan, 1984; Michie, 1980; Shortliffe, Buchanan, and Feigenbaum, 1979; Webster and Miner, 1982). It is one area of artificial intelligence that appears to have come into its own and to be ready for application to the development of operational systems. There are a number of very helpful tools available for use in building expert systems, although selection among available tools must still be done knowledgeably and with reference to the particular domain for which a system is to be built. This decision, in turn, depends upon an understanding of the problem domain sufficient to permit choices among alternative system architectures to accommodate alternative ways of acquiring, representing, and utilizing expert knowledge for purposes of system development and implementation. There does not exist a general-purpose system that may be used in all problem domains and operational environments to perform all necessary functions of knowledge-based expert system development. System development thus depends upon professionals who can deal effectively with issues relating both to human knowledge and expertise and to its elicitation and representation in computer software for effective utilization. This may well be one of today's most important human factors problems.

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Decision Science Consortium, Inc.
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Dr. Anthony Ephremides
University of Maryland
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College Park, MD 20742

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Code 03T
Hoffman Building II
Alexandria, VA 22332

Dr. Baruch Fischhoff
Decision Research
1201 Oak Street
Eugene, OR 97401

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Naval Electronics Systems Command
Code 613
Washington, DC 20363

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Perceptronics, Inc.
6271 Variel Avenue
Woodland Hills, CA 91364

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Code 252
Office of Naval Research
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Arlington, VA 22217

Mr. Jeffrey Grossman
Human Factors Branch
Code 3152
Naval Weapons Center
China Lake, CA 93555

Dr. Bruce Hamill
The Johns Hopkins University
Applied Physics Laboratory
Johns Hopkins Road
Laurel, MD 20707

Mr. Paul Heckman
Naval Ocean Systems Center
San Diego, CA 92152

Dr. James H. Howard, Jr.
Department of Psychology
Catholic University
Washington, DC 20064

CDR. Kent S. Hull
NASA-Ames Research Center
MS 239-21
Moffett Field, CA 94035

Human Factors Engineering
Code 441
Naval Ocean Systems Center
San Diego, CA 92152

Human Factors Engineering Branch
Code 4023
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Point Mugu, CA 93042

Human Factors Technology
Administrator
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Code MAT 0722
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Human Factors Department
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Dr. Douglas Jensen
Carnegie Mellon University
Computer Science Department
Pittsburgh, PA 01803

Dr. Edgar M. Johnson
Technical Director
U. S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Edward R. Jones
Chief, Human Factors Engineering
McDonnell-Douglas Astronautics Co.
St. Louis Division
Box 516
St. Louis, MO 63166

CDR. Tom Jones
Naval Air Systems Command
Human Factors Programs
NAVAIR 330J
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Dr. Clinton Kelly
Defense Advanced Research Projects
Agency
1400 Wilson Boulevard
Arlington, VA 22209

Dr. J. S. Lawson
Naval Electronic Systems Command
NELEX-06T
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Dr. Leslie Lamport
SRI International
Computer Science Laboratory
333 Ravenswood Avenue
Menlo Park, CA 94025

Mr. R. Lawson
ONR Detachment
1030 East Green Street
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Dr. David Noble
Engineering Research Associates
8616 Westwood Center Drive
McLean, VA 22180

CDR. James Offutt
Office of the Secretary of Defense
Strategic Defense Initiative
Organization
Washington, DC 20301-7100

Dr. Jesse Orlansky
Institute for Defense Analyses
1801 N. Beauregard Street
Alexandria, VA 22043

Dr. Richard Pew
Bolt, Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02238

Physiology Program
Office of Naval Research
Code 441NP
800 North Quincy Street
Arlington, VA 22217

Dr. Gary Poock
Operations Research Department
Naval Postgraduate School
Monterey, CA 93940

Mr. John Quirk
Naval Coastal Systems Laboratory
Code 712
Panama City, FL 32401

Dr. Andrew Rechnitzer
Office of the Chief of Naval
Operations, OP952F
Naval Oceanography Division
Washington, DC 20350

Dr. William B. Rouse
School of Industrial and Systems
Engineering
Georgia Institute of Technology
Atlanta, GA 30332

Dr. T. B. Sheridan
Dept. of Mechanical Engineering
Massachusetts Institute of
Technology
Cambridge, MA 02139

Dr. A. L. Slafkosky
Scientific Advisor
Commandant of the Marine Corps
Code RD-1
Washington, DC 20380

Dr. Robert G. Smith
Office of the Chief of Naval
Operations, OP987H
Personnel Logistics Plans
Washington, DC 20350

Dr. Harry Snyder
Dept. of Industrial Engineering
Virginia Polytechnic Institute
and State University
Blacksburg, VA 24061

Special Assistant for Marine Corps
Matters
Code 100M
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

Mr. H. Talkington
Engineering & Computer Science
Code 09
Naval Ocean Systems Center
San Diego, CA 92152

Technical Director
U. S. Army Human Engineering Labs
Aberdeen Proving Ground, MD 21005

Dr. Douglas Towne
University of Southern California
Behavioral Technology Lab
3716 S. Hope Street
Los Angeles, CA 90007

Dr. Amos Tversky
Dept. of Psychology
Stanford University
Stanford, CA 94305

U.S. Air Force Office of
Scientific Research
Life Science Directorate, NL
Bolling Air Force Base
Washington, DC 20332

Dr. Robert Wherry
Analytics, Inc.
2500 Maryland Road
Willow Grove, PA 19090

Dr. Christopher Wickens
Department of Psychology
University of Illinois
Urbana, IL 61801

Mr. Joseph G. Wohl
Alphatech, Inc.
3 New England Executive Park
Burlington, MA 01803

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